Earth Surface Processes and Landforms
Earth Surf. Process. Landforms **24**, 943–955 (1999)

A TWO-PARAMETER WEIBULL FUNCTION TO DESCRIBE AIRBORNE DUST PARTICLE SIZE DISTRIBUTIONS

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Received 8 December 1998; Revised 6 April 1999; Accepted 12 May 1999

ABSTRACT

A number of mathematical distributions have been proposed for the description of the particle size distribution of unconsolidated sediments. However, few studies have mathematically described aeolian dust particle size distributions. Recent work has shown mathematically how the sequential fragmentation of materials leads to a Weibull distribution. Since the breakage of aggregates by saltating grains is a primary mode of aeolian dust production, we test the hypothesis that the Weibull distribution may be used to describe airborne soil grains. Surface samples were collected from 52 sites including soils, dirt roads and roadside ditches in the Southern High Plains of west Texas. The samples were tumbled in the Lubbock dust generation, sampling and analysis system to generate a dust cloud. The particle size distribution of the dust was measured *in situ* by laser diffraction and PM_{10} concentration was determined gravimetrically (PM_{10} = airborne particulate matter with diameter ≤ 10 μm). This study demonstrated that the Weibull cumulative distribution function (c.d.f.) is an excellent choice to describe the particle size distribution of dust suspended from mineral sediment. A Weibull c.d.f. used to describe the dust cloud size distribution, accounted for 94 per cent of the variation in estimates of particles ≤ 50 μm diameter. The fraction of dust particles ≤ 10 μm diameter, as estimated using the Weibull, was not correlated to suspended PM_{10} concentration. However, the fraction of particles ≤ 10 μm was correlated with properties of the sediment from which the airborne dust was derived. As clay content increased, the total amount of suspended dust increased and the fraction of suspended particles ≤ 10 μm in the dust cloud decreased. Analyses of variance showed no significant differences ($P < 0{\cdot}05$) among sampling locations (roads vs ditches vs soils) for cumulative fraction values for $\leq 2{\cdot}5$, ≤ 10, ≤ 25, ≤ 30 and ≤ 50 μm diameter particles. However, the PM_{10} concentration values were significantly different among dust generated from these locations. The road samples produced about twice the amount of PM_{10} (490 mg m^{-3}) as the soil or ditch samples (235 mg m^{-3}). Published in 1999 by John Wiley & Sons, Ltd.

KEY WORDS: particulate matter; suspension; wind erosion; aeolian transport; Weibull; PM_{10}; dust

INTRODUCTION

Dust emissions of suspended particles (aeolian dust) from erosive winds on bare soils and dirt roads are very common in many regions around the world. Recently, concern for the health and climatic impact of aeolian dust has produced increased interest in this subject. Field studies of aeolian dust produced at or near the source of intense dust storms are difficult to conduct and few results have been reported (Gillette and Walker, 1977; Nickling, 1983; Fryrear, 1995; Gillies *et al.*, 1996; Leys and McTainsh 1996; Stout and Zobeck, 1996). Efforts are now underway to develop equipment and methods of analysis of aeolian dust under more controlled laboratory conditions. Such analyses are needed to relate aeolian dusts to their source sediments. Knowledge of the dust source will facilitate the development of sound mitigation strategies to reduce air pollution from blowing dust.

A wide variety of devices have been proposed in the past to evaluate aeolian dust in the laboratory (Gill *et al.*, 1999). A rotating drum-type device (the Lubbock dust generation, sampling and analysis system) was

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CCC 0197-9337/99/100943–13 $17.50

recently developed to create and perform *in situ* particle size analysis of dust (Gill *et al.*, 1999; Zobeck *et al.*, 1997). The device was used in the particle size analyses of soils and dirt road surfaces and demonstrated that mean dust size varied with soil texture and other physical and chemical sediment source characteristics (Zobeck *et al.*, 1997).

The Lubbock dust generation, sampling and analysis system determines the dust particle size distribution and concentration of PM_{10} of suspended dust. PM_{10} refers to airborne particulate matter with an aerodynamic diameter equal to or smaller than 10 microns (μm). In 1987, as part of the National Ambient Air Quality Standards (NAAQS), the United States federal government issued regulations governing PM_{10} as a primary air pollutant. Small airborne particles in the PM_{10} range are capable of being transported long distances by the wind, having potential impacts over a large area and for a long time. Environmental health studies have indicated that PM_{10} is inhaled deeply enough into the human lower respiratory tract that it may adversely impact health (Gordian *et al.*, 1996; Pope *et al.*, 1996). In addition, the potential climatic impact of wind-eroded mineral dusts from disturbed soils has also been recognized (Tegen *et al.*, 1996).

Several factors, such as wind velocity and source sediment texture, are important in determining the size distribution of aeolian dust. Dust is sorted by the wind as it travels away from the source (Cooke *et al.*, 1993), decreasing in particle size with distance (Tsoar and Pye, 1987). The wind velocity producing the dust can also affect the size distribution. At moderate wind velocity (friction velocity = $0{\cdot}29$ m s^{-1}), dust measured at a height of 1·5 m above a loamy fine sand soil had a bimodal particle size distribution (Gillette and Walker, 1977). The particle size distribution became unimodal at a friction velocity of $0{\cdot}45$ m s^{-1}. The same study found dust from a loamy fine sand soil produced a higher percentage of clay (dust particles smaller than 2 μm in diameter) than that from a coarser fine sand soil. Nickling (1983) discovered that little clay was found in dust produced by coarse silt and fine sand sediments.

Many mathematical distributions have been proposed for the description of the particle size distributions of sediments in general (Cooke *et al.*, 1993). These distributions include the conventional Gaussian or normal, log-normal (Shirazi and Boersma, 1984; Buchan, 1989), modified log-normal (Wagner and Ding, 1994), log-hyperbolic (Hartmann and Christiansen, 1988), bi- or multimodal (Pinnick *et al.*, 1985), Rosin-Rammler (Kittleman, 1964) distributions and others. Although many authorities have presented data on the size distribution of dust deposits (Swineford and Frye, 1945; Zeuner, 1949; Péwé, 1981; Péwé *et al.*, 1981; Wilshire *et al.*, 1981; D'Almeida and Schütz, 1983), few have presented mathematical formulations of dust particle size distributions related to processes associated with the creation of the dust.

Patterson and Gillette (1977) described aeolian dust using a log-normal distribution based on work by Epstein (1947), who suggested that breakage mechanisms such as sandblasting lead asymptotically to log-normal distributions. More recently, in their study of the particle size distribution of volcanic ash, Wohletz *et al.* (1989) have shown mathematically how the sequential fragmentation of materials leads to a Weibull distribution. The Weibull function (Weibull, 1951) was originally used to characterize 'the size effect on failures in solids' in other words, the sequential fragmentation of materials. Brown and Wohletz (1995) pointed out that since the Rosin-Rammler is the integral form of the Weibull, it too has a physical basis. They maintain that the successful use of the log-normal distribution to describe fragmentation distributions may have been simply fortuitous.

In the geosciences, the Weibull distribution has been used to describe the size distributions of fractured rock (Boadu and Long, 1994; Froehlich and Benson, 1996) and fractured ice (Tuhkuri, 1994), as well as volcanic ash (Wohletz *et al.*, 1989). Perfect and Kay (1995) used conventional and modified Weibull distributions to describe the breakdown of soil aggregates by brittle fracture. However, the Weibull cumulative distribution function (c.d.f.) has not been widely used in the characterization of aeolian sediments. Since the breakage of aggregates by saltating grains is a primary mode of aeolian dust production, and 'the breakup of a single particle into finer particles,' is the physical basis of the Weibull, as described by Brown and Wohletz (1995), the Weibull distribution would appear to be appropriate in the description of airborne soil grains. In this study, we evaluate the Weibull c.d.f to describe dust particle size distributions generated from Southern High Plains sediments by the Lubbock dust generation, sampling and analysis system and other dust distributions described in the literature. In addition, we relate particle size distributions to PM_{10} concentrations and to sediment source characteristics.

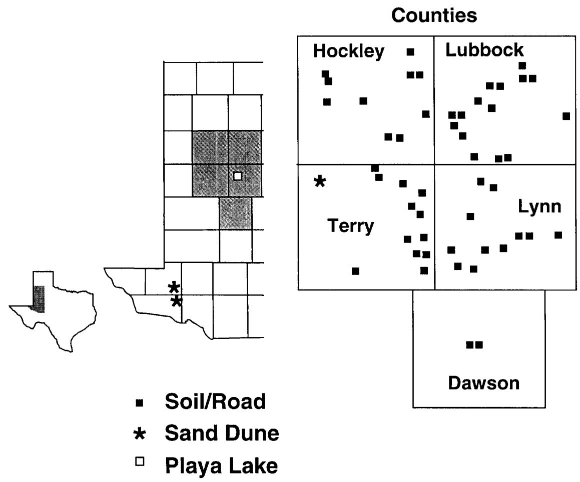

Figure 1. Location of the study sites in west Texas

MATERIALS AND METHODS

Sample selection and preparation

Sampling sites were identified to the west and south of Lubbock, Texas, where surface soils generally have a high (45–95 per cent) sand content (Lee *et al.*, 1994). United States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) soil surveys and USDA-NRCS District Conservationists were consulted in the four counties south and west of Lubbock, Texas (Lubbock, Hockley, Terry and Lynn Counties). Sampling sites (Figure 1) included agricultural land, sand drifts and dunes, a playa lake surface, and unpaved road surfaces and roadside ditches in the four-country area, as well as dunes along the southwestern edge of the Southern High Plains in western Texas. In this study, 52 different sites were sampled: 38 from agricultural land, sand drifts and dunes, and a playa lake (soils); 15 road surfaces (roads); and nine roadside ditches (ditches). Sites were sampled between January and April 1996 when fields were generally fallow, naturally dry and free of growing vegetation. These samples were selected from a slightly larger data set described by Zobeck *et al.* (1997). The samples used in this study included only those sites where at least 400 g of sediment were collected and used for dust generation.

To minimize contamination of the samples taken from agricultural land by sediments recently blown onto them from upwind, approximately 5 cm depth of soil was removed from the surface at each site and discarded. Samples were then collected with a shovel from a layer 5 cm in thickness below the removed portion. Five points on a diamond-grid pattern were collected and composited for each soil site. For unpaved road and ditch sediments, samples were gently swept directly into a dustpan with a plastic fibre broom in a linear swathe across the entire loose surface from edge to edge. All samples were dried to a moisture content of less than 2 per cent by weight in the laboratory. Dry soil aggregates (clods) were crushed to pass through a 2 mm sieve and stored in clean plastic bags. Coarse materials that would not pass (rock fragments, vegetative residue, etc.) were removed.

Particle size distribution analyses were made using a modified Bouyoucos (1951) method. Sand content was determined by wet sieving, and silt and clay content were determined by hydrometer. Each sample was designated a texture according to the USDA classification system (Soil Survey Staff, 1993). Except for Randall clay (typical of dry playa lake surfaces), all samples of soil, road and ditch surfaces ranged between sandy clay loam and sand in texture. Organic carbon content was determined with a modified Walkley-Black procedure (Allison, 1965), and calcium carbonate equivalent was determined using the acid neutralization method of the US Salinity Laboratory (1954).

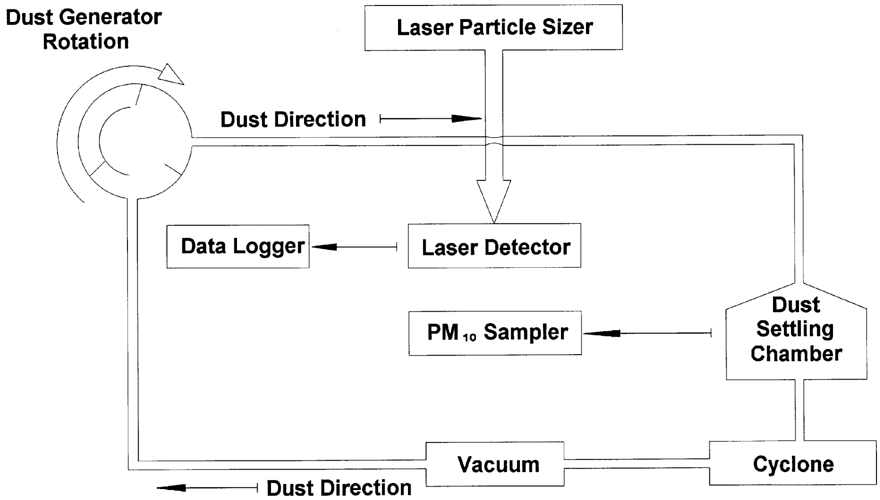

Figure 2. Schematic diagram of the Lubbock dust generation, sampling and analysis system

Dust was suspended from the source samples and analysed in the Lubbock dust generation, analysis and sampling system (Figure 2) as summarized below. To generate airborne dust, a 400 g sediment sample was placed in a large rotating-barrel dust generator (Singh *et al.*, 1994) of a type similar to those used to measure 'dustiness' of materials in occupational health studies (Chung and Burdett, 1994; Hjemsted and Schneider, 1996). The dust was generated by the impact of grains falling from the top to the bottom of the barrel, shown experimentally by Singh *et al.* (1994) to simulate the release of dust in an energetic saltation process. The impact velocity of samples in this dust generator was calculated by Singh (1994) to be equivalent to the impact velocity from saltation for a friction velocity of 0·6 m s^{-1}, well over the threshold for materials in the Southern High Plains and typical of a moderate to strong dust storm. Dust suspended by the impacts was entrained by airflow and conveyed through a pipe into the particle measurement portion of the system. The particle size distribution of the suspended grains was measured as equivalent volume spherical diameters by laser diffraction (Malvern model 2600). The suspended dust then entered a settling chamber, wherein a low-volume (5 l min^{-1}) aerosol sampler ('MiniVol,' Air Metrics Inc.) collected PM_{10} by impaction for 5 min onto a 47 mm diameter polycarbonate filter. The mass of dust collected on the filters was determined gravimetrically for filters desiccated to constant weight at 30 per cent relative humidity.

The dust generator rotated at 13 r.p.m., providing 40 particle impacts per minute. Thirty seconds after rotation began, the laser diffraction particle sizer and PM_{10} sampler were activated and run for 5·0 min. Airflow to the dust generator was 0·4 m^3 min^{-1}. The laser diffraction spectrometer was run in model-independent, particle-in-air mode for each sample, as recommended for this instrument when measuring dust suspensions (Hamidi and Swithenbank, 1986). The 100 mm receiver lens was used to measure particles from the PM_{10} range up to 188 μm, as suggested by Singer *et al.*, (1988). Two separate dust-particle-diameter data sets were collected for each run of the instrument. The first data set measured particles from 0·5 to 2·0 min after dust generation started, while the second data set measured particles 3·0 to 4·5 min after the system was activated.

Distribution of particle size

The cumulative particle size distribution for each dust sample was fitted to a two-parameter Weibull c.d.f. of the form:

$$y = 1 - e^{-(x/b)^c} \tag{1}$$

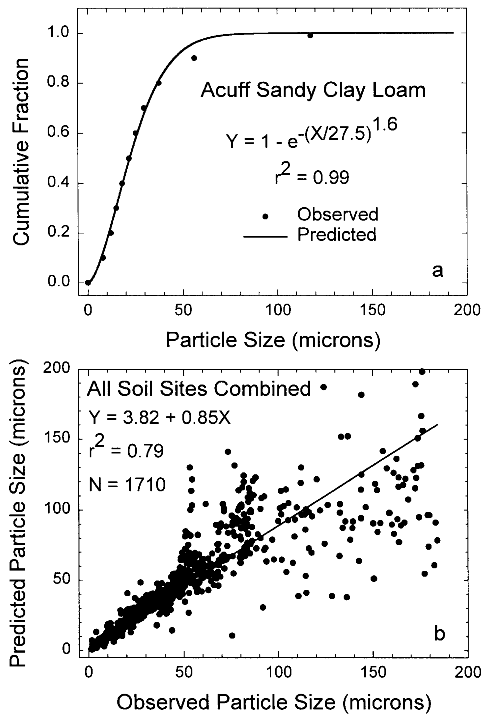

Figure 3. (a) Cumulative particle size distribution of an Acuff sandy clay loam. The observed data were measured using laser diffraction; the predicted data were estimated using a Weibull cumulative distribution function. (b) Observed versus predicted particle size of dust from soil locations

where y is the predicted cumulative fraction smaller than particle size x (in μm), the b parameter is a scale factor, and the c parameter is a shape factor (Johnson and Kotz, 1970). A unique Weibull cdf was determined for each sample run. The parameters were estimated for each sample by regressing the cumulative fractions 0·10, 0·20, 0·30, 0·40, 0·50, 0·60, 0·70, 0·80, 0·90 and 0·99 against the observed particle size at that fraction. The predicted cumulative fraction was then evaluated for particle diameters $\leq$2·5, $\leq$10, $\leq$25, $\leq$30, $\leq$50 μm for each sample.

Statistical procedures

The roads, ditches and soil locations were compared for a limited number of sites having observations with all three locations (roads, ditches and soils) in close proximity (*c*. 100 m). Separate univariate analyses of variance for roads, ditches and soils were conducted on fractions of particle sizes $\leq$2·5, $\leq$10, $\leq$25, $\leq$30 and $\leq$50 μm with the factors USDA texture group, site within texture group, and run number within site. For PM_{10} concentration, only one sample was collected for each run and so the factors were texture group and site within texture group. Multivariate analyses of variance on the b and c parameters of the Weibull were performed separately for roads, ditches and soils with the factors texture group, site within texture group, and run number within site. An effect was judged significant when $P < 0{\cdot}05$.

For soil locations, simple linear regression and correlation of soil chemical and physical variables with particle size variables were performed for all texture groups combined and separately. The null hypothesis, $r = 0$, was tested with $P<0{\cdot}05$. The variance of residuals was homogeneous for particle sizes $\leq$50 μm diameter. For particle sizes >50 μm diameter, the variance increased with increasing particle size. Various transformations of the data to alleviate this condition produced no improvement in the variance of the residuals for particle sizes greater that 50 μm diameter.

RESULTS AND DISCUSSION

Distribution of particle size

Figure 3a shows an example of a particle size distribution for an Acuff sandy clay loam sample with the Weibull cdf fitted to the data. This example is typical of the fit of the Weibull cdf to individual samples, producing a high r^2 and close estimates for the small size fractions. In an effort to evaluate how well the Weibull cdf fitted the data for all sites, the Weibull cdf for each sample distribution was also used to estimate the particle size at the same cumulative fraction values measured by the Malvern (0·10, 0·20, 0·30, 0·40, 0·50, 0·60, 0·70, 0·80, 0·90 and 0·99). Figure 3b shows a comparison of the predicted particle size with the observed size. For particle sizes ≤ 50 μm the fit was good for both the individual sample fit (Figure 3a) and for all soil sites combined (Figure 3b). Particle sizes > 50 μm had a much poorer fit.

The reason for the poor fit at the larger particle sizes is not known but we suspect it is related to particle transport mechanics. We believe the smaller particles were easily entrained in the air stream in suspension. The larger particles may have been more affected by gravity and were transported in short-term suspension or saltation mode. Data by Tsoar and Pye (1987) suggest there is no sharp distinction between saltation and suspension and, depending on the wind velocity, 50 μm diameter particles may be in suspension or saltation. Thus, many of the larger particles may have remained saltating in the dust-generating chamber, unable to follow the air stream through the exit from the rotating drum into the laser particle sizing portion of the system. Tests of this hypothesis were beyond the scope of this study.

The regression of predicted particle size on observed particle size (Figure 3b) suggests that when using all of the observed particle size data, the smallest predicted particle size is 3·82 μm. Since 50 μm is the upper limit of the silt-sized particles in the USDA classification system and the variation of particles greater than 50 μm is greater than smaller particles, we regressed the predicted particle size on observed particle size for observed particles ≤ 50 μm. Separate analyses were performed for soils, roads and roadside ditches. These regressions clearly demonstrated the utility of using the Weibull cdf to estimate dust particles for particles ≤ 50 μm diameter. Plots of the residuals produced in these regressions (Figure 4) show that in all cases, the Weibull cdf accounted for over 90 per cent of the variation of the data ($r^2 > 0{\cdot}9$) and the smallest predicted particle size was very close to 0 (0·38 μm for soils).

Since the log-normal cdf has been used to describe dust distributions in the past (c f. Patterson and Gillette, 1977), we compared a two-parameter log-normal distribution to the two-parameter Weibull distribution described by equation 1 for all of the data using all samples evaluated in this study. The two-parameter log-normal cdf used was of the form:

$$y = 1/(a^* \sqrt{2^* \pi})^* e^{(-(\mathrm{Log(x)} - b)^2/2^* a^2)} \tag{2}$$

where y is the predicted cumulative fraction smaller than particle size x (in μm) and a and b are regression parameters. Equation 2 was evaluated by taking the log of the independent variable of the definite integral of the cumulative normal distribution function as described by Mendenhall and Scheaffer (1973).

In this comparison, the Weibull cdf had a higher r^2 than the log-normal cdf in 51 out of 52 sample sites tested (98 per cent). The r^2 for the Weibull distributions varied from 0·800 to 0·999 and the r^2 for the log-normal distributions varied from 0·532 to 0·991. A typical comparison of the Weibull cdf and the log-normal cdf is illustrated in Figure 5 (Mankser fine sandy loam, sampled in Lubbock County). Note the relatively poor fit for the log-normal distribution at the lower and upper ends of the curve even though both distributions had r^2 over 0·97. The clear tendency for the Weibull cdf to fit better than the log-normal cdf throughout the entire range of the data strongly supports the use of the Weibull cdf for describing dust distributions.

Although the results in the study showed that the Weibull cdf worked best for particles with aerodynamic diameter less than 50μm, additional tests of dust distributions with a wider range of particle sizes further demonstrated the value of the Weibull cdf in describing dust particle size distributions. We tested the Weibull cdf described in Equation 1 against several dust-related data sets described in the literature with reasonable results. Dust data sets from deserts in Algeria (0 to 310 μm) and Senegal (0 to 60 μm; D'Almeida and Schütz,

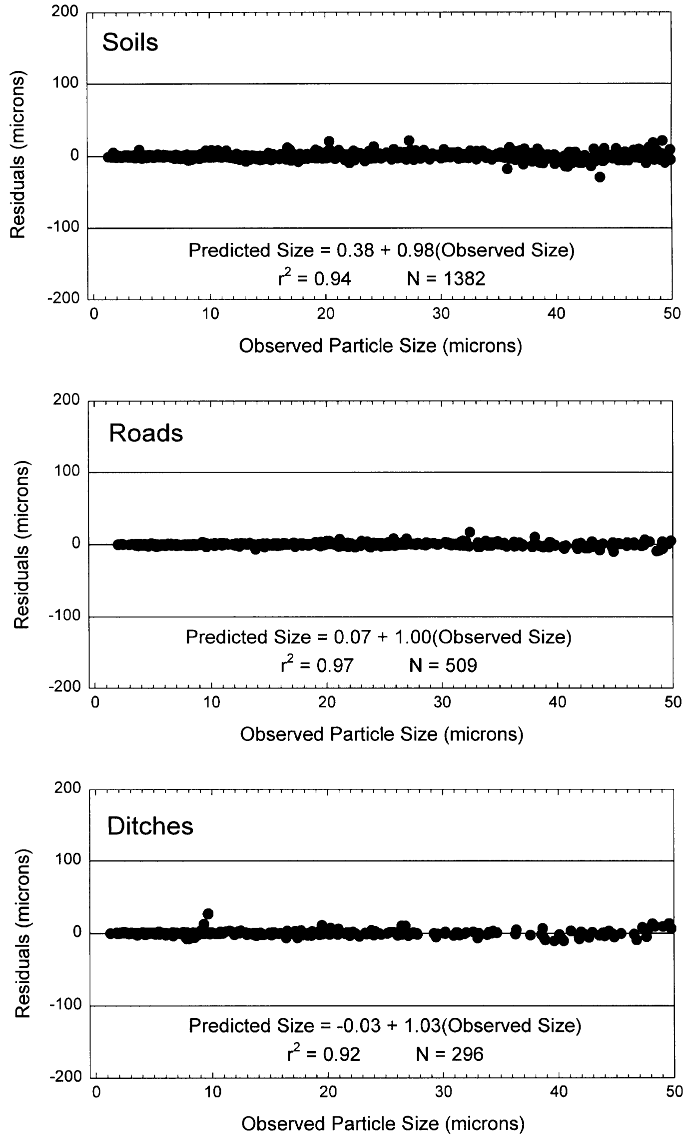

Figure 4 Plots of residuals of observed versus predicted particle size for observations less than or equal to 50 μm by sampling location

1983) fit the Weibull cdf with r^2 exceeding 0·98. Several dust size distribution data sets are described in Péwé (1981) in sufficient detail for testing. The Weibull cdf fit dust data from Germany (0 to 78 μm; Zeuner, 1949), Kansas (0 to 75 μm; Swineford and Frye, 1945), Arizona (0 to 56 μm; Péwé *et al.*, 1981), California (0 to 95 μm; Wilshire *et al.*, 1981), Israel (0 to 63 μm; Yaalon and Ganor, 1979), and loess from Siberia (0 to 66 μm; Péwé *et al.*, 1981) with r^2 greater than 0·95.

Location and texture effects

Analyses of variance showed no significant differences ($P < 0{\cdot}05$) among sampling locations (roads vs ditches vs soils) for cumulative fraction values for $\leq 2{\cdot}5$, ≤ 10, ≤ 25, ≤ 30 and ≤ 50 μm diameter particles. However, the PM_{10} concentration values were significantly different among locations at the $P = 0{\cdot}0512$ level, thus we compared differences among locations individually (Figure 6). The road samples produced about

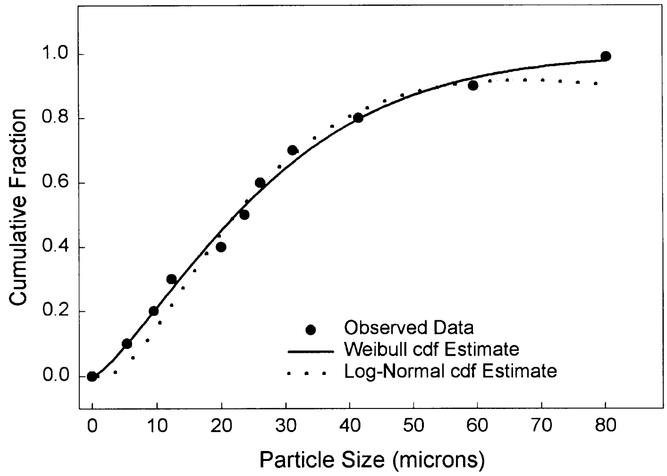

Figure 5. Comparison of the Weibull cumulative distribution function estimate ($r^2 = 0{\cdot}993$) and a log-normal cumulative distribution function estimate ($r^2 = 0{\cdot}976$) for dust derived from a Mankser fine sandy loam

twice the amount of PM_{10} as the soil or ditch samples. The soil samples were not significantly different ($P < 0{\cdot}05$) from the ditch samples.

Since sediment locations were not equally represented in the data set, separate analyses of variance were performed for roads, ditches and soils (Table I). In the analyses of the particle fractions observed, texture group had little effect for any particle size when the site was either a road or a ditch. However, site within texture group was significant for most tests. This means the variation in the data was quite large. The variation between sites within a texture group was greater than or equal to the variation between texture groups. For soil locations, texture group and site both produced significant effects for particle sizes $\leq 2{\cdot}5$ μm and ≤ 10 μm diameter, but only site was significant for particle sizes ≤ 25, ≤ 30 and ≤ 50 μm. These results suggest that for only soil locations, differences in the fractions of $\leq 2{\cdot}5$ μm and ≤ 10 μm diameter dust particles, but not larger particles, were dependent on the texture of the source sample. Taking a second observation of particle size distribution (run within site) did not produce significantly different results in this study.

Differences in PM_{10} concentration were observed for texture groups and sites within texture groups for soils and for texture groups of roads. No differences in PM_{10} were observed among ditches. There was considerable overlap in measured PM_{10} concentration among USDA texture groups (Figure 7). Mean PM_{10} concentration by texture group varied from 35 mg m^{-3} for clay soils to 500 mg m^{-3} for sandy clay soils. In general, PM_{10} concentration increased with increasing clay content with the exception of the clay soil samples. In this study, the clay samples were collected in a non-calcareous playa lakebed. The soil formed very stable aggregates that were very resistant to abrasion. Conversely, the sandy clay soils were highly calcareous (over 15 per cent calcium carbonate), had low stability, and were easily abraded.

The differences in PM_{10} among texture groups shown in Figure 7 suggest that the groups may be placed in three broad classes: non-calcareous clays, sands and fine sands; loamy fine sands and fine sandy loams; and the loams, sandy clay loams and calcareous sandy clays. Figure 8 shows the Weibull cdf for the three groups. The PM_{10} fraction of the loams (0·20) was about one-half that of the sands (0·40), with the loamy fine sands and fine sandy loams intermediate.

Correlations of particle size variables with selected soil physical and chemical properties are presented in Table II. None of the particle size fractions listed in Table II was significantly correlated with PM_{10} concentration. However, PM_{10} concentration was correlated with various source sediment particles size fractions, organic carbon, and calcium carbonate ($CaCO_3$) content. PM_{10} concentration was positively correlated with percentage very fine sand (v.f.s.), clay, sum of particles < 100 μm, sum of particles < 100 μm plus $CaCO_3$, organic carbon, and $CaCO_3$, and was negatively correlated with percentage sand. Conversely,

Table I. Analyses of variance for ditch, road, and soil samples

Location	n	Source of variation	Fraction ≤ 2.5 μm	Fraction ≤ 10 μm	Fraction ≤ 25 μm	Fraction ≤ 30 μm	Fraction ≤ 50 μm	PM_{10} concentration
Ditches	36							
		Texture group	0·2393	0·1330	0·5917	0·6681	0·6185	0·1025
		Site within Texture group	0·0374*	0·1925	0·0037*	0·0022*	0·0008*	0·6097
		Run within Site	0·6834	0·2942	0·9239	0·9487	0·9794	
Roads	56							
		Texture group	0·1508	0·2629	0·6581	0·7314	0·6397	0·0438*
		Site within Texture group	0·0150*	0·0101*	0·0218*	0·0284*	0·1746	0·8750
		Run within Site	0·2959	0·6144	0·9570	0·9710	0·9803	
Soils	178							
		Texture group	0·0001*	0·0233*	0·2186	0·4520	0·6884	0·0001*
		Site within Texture group	0·0094*	0·0001*	0·0001*	0·0001*	0·0001*	0·0035*
		Run within Site	0·9995	0·9947	0·9079	0·9294	0·9920	

* Indicates significant effect at $P < 0.05$

fraction of particles ≤ 2.5 μm was negatively correlated with percentage silt, v.f.s., silt plus v.f.s., clay, sum of particles <100 μm, sum of particles <100 μm plus $CaCO_3$, and $CaCO_3$, and was positively correlated with percentage sand. The fraction of particles ≤ 10 μm had the same correlations as the particle size ≤ 2.5 μm with the exception that no correlation was found with percentage silt and organic carbon. Few correlations were found for the other particle size variable classes tested.

These correlations show that while the mass of airborne PM_{10} increased as the amount of particles ≤ 100 μm, organic matter and $CaCO_3$ increased in the source sample, the volume fraction of airborne particles ≤ 10 μm diameter decreased. This indicates that as the amount of particles ≤ 100 μm, organic matter and $CaCO_3$ increased in the source sample, the total amount of airborne dust increased, with a proportionally greater increase in the volume fraction of particles larger than 10 μm diameter.

The increase in PM_{10} concentration with increasing organic carbon was unexpected and may be an artefact of sampling the relatively small range in organic carbon found in the soils of this region. Organic carbon ranged from 1 to 13 g kg^{-1} for the soils tested in this study. The range in $CaCO_3$ in the calcareous soils was quite large, varying from 6 to 250 g kg^{-1}.

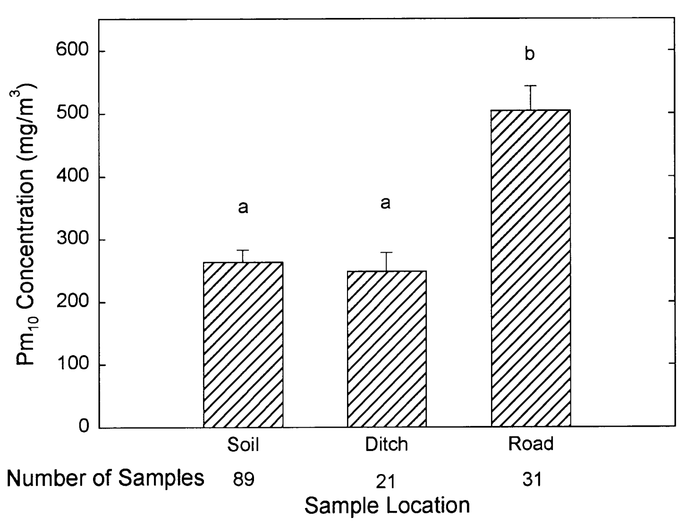

Figure 6. PM_{10} concentration by sampling location. Locations with the same letter are not significantly different at the $P = 0.05$ level

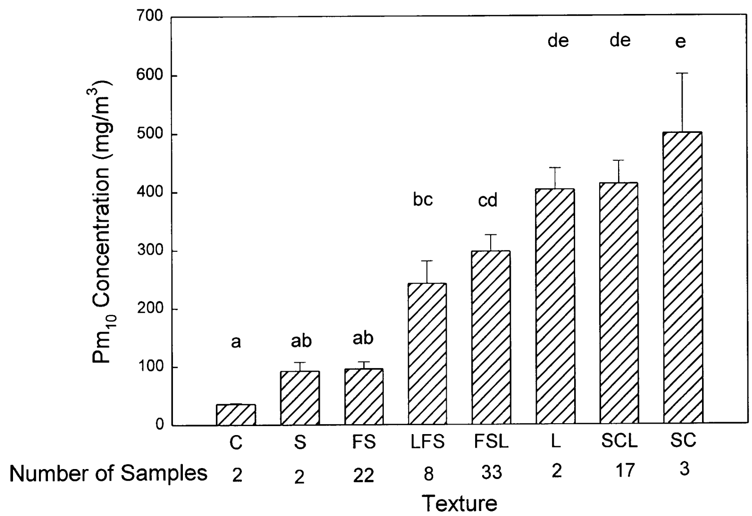

Figure 7. PM_{10} concentration by USDA texture class. Textures with the same letter are not significantly different at the $P = 0{\cdot}05$ level. (C = clay, S = sand, FS = fine sand, LFS = loamy fine sand, FSL = fine sandy loam, L = loam, SCL = sandy clay loam, SC = sandy clay)

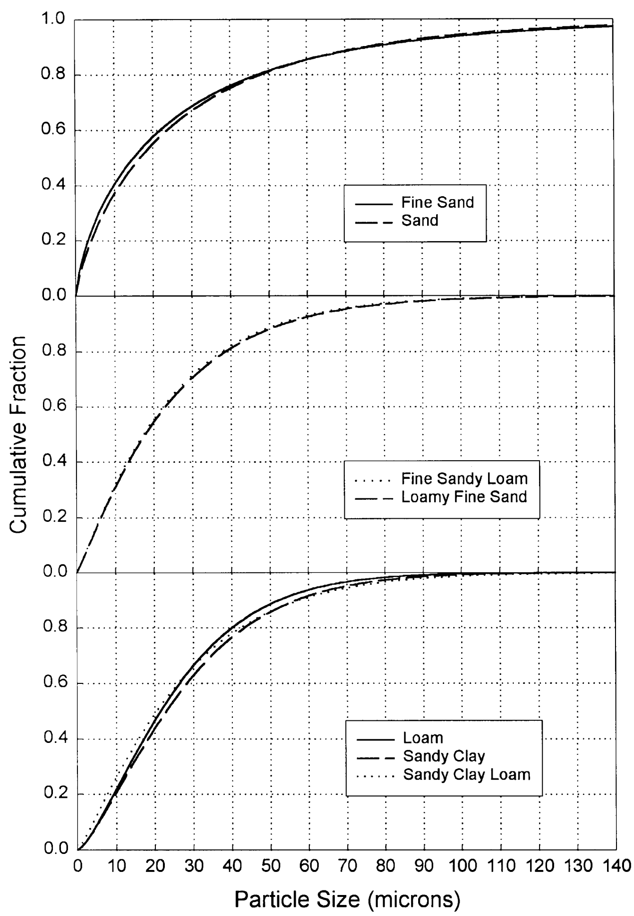

Figure 8. Cumulative particle size distribution of dust samples by USDA texture class

Table II. Correlation of particle size variables with selected soil physical and chemical properties. Sample size varied from 40 to 44, depending on soil property correlated.

Particle size variables	Percent silt	Percent vfs	Percent silt + vfs	Percent clay	Percent sand	Percent < 100 μm	Percent < 100 μm + $CaCO_3$	Percent $CaCO_3$	Percent organic carbon
PM_{10} concentration	–	0·495	–	0·573	−0·436	0·389	0·411	0·319	0·467
<2·5 μm fraction	−0·316	−0·548	−0·406	−0·409	0·382	−0·443	−0·388	–	−0·309
<10 μm fraction	–	−0·510	−0·314	−0·343	0·333	−0·355	−0·321	–	–
<25 μm fraction	–	−0·414	–	–	–	–	–	–	–
<30 μm fraction	–	−0·360	–	–	–	–	–	–	–
<50 μm fraction	0·330	–	–	–	–	–	–	–	0·354

vfs = Very fine sand; $CaCO_3$ = calcium carbonate; – = no correlation

CONCLUSIONS

This study demonstrated that the Weibull cdf accurately describes the particle size distribution of dust suspended from mineral sediment. The Weibull c.d.f accounted for more of the variation in the data (higher r^2) than a log-normal c.d.f in 98 per cent of the individual sample distributions of dust created by the Lubbock dust generation, sampling and analysis system. The Weibull c.d.f also fits the data much better than the log-normal c.d.f at the extremes of the observed values. In an evaluation of all of the data combined, the Weibull c.d.f accounted for 94 per cent of the variation in estimates of particles $\leq$50 μm diameter. Estimates of particles with diameters greater than 50 μm deviated somewhat from their predicted values, possibly due to differences in transport processes for larger particles. Further support for the utility of the Weibull c.d.f was demonstrated by how well it fitted for many dust distributions described in the literature.

Use of the Weibull permits the calculation of the fraction of any particle size from the estimated distribution, within the limits of the observed data. The fraction of dust particles $\leq$10 μm diameter, as estimated using the Weibull, was not correlated to suspended PM_{10} concentration measured by the PM_{10} sampler. However, the fraction of particles $\leq$2·5 μm and $\leq$10 μm was correlated with properties of the sediment from which the airborne dust was derived. The texture of the source sediment was an important determinant for the fraction of airborne particles $\leq$2·5 μm and $\leq$10 μm for soils but was not a significant factor for roads and roadside ditches. For soils, as clay content increased, the total amount of suspended dust increased, but the fraction of suspended $\leq$2·5 and $\leq$10 μm particles in the dust cloud decreased. The lack of significance for roads and ditches was attributed to the narrow range in texture found in these sediments.

ACKNOWLEDGEMENTS

Textural, organic carbon and calcium carbonate analyses of soil, ditch and road samples were performed by B.L. Allen, Department of Plant and Soil Science, Texas Tech University, Lubbock. We thank D. Holder, B. Lamblin, J. Lee, E, Monson, J. Stout, W. Waybright and M. Zhang, for field, laboratory and technical assistance. We thank the USDA-NRCS Conservationists Mickey Black, Mario Avila, Gerald McMasters, Duane Moss and Randy Underwood who helped us identify sampling sites and joined us in the field. We appreciate the cooperation of Dr Wayne Keeling and the Texas Agricultural Experiment Station–Lubbock, the Texas Parks and Wildlife Department, as well as many landowners in the region, for access to their property.

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